Clay Stabilization with Portland Cement
Richland County Montana 2010-2021
(2023 Final Summary Report)

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Introduction

In 2009, Richland County faced rapidly increasing truck traffic on gravel roads caused by oil field development and resource extraction in the Bakken Formation. Limited rock resources within reasonable haul distances and budget limitations were issues for road repair and maintenance. The county considered both traditional paving and stabilization of the lean clay subgrades to address road deterioration. Traditional paving was determined too expensive due to haul costs and also would require subgrade widening for thick aggregate base layers.

Unconfined strength testing of subgrade clays with various traditional and non-traditional agents indicated Portland Cement was the most promising option. Subgrade clay soils have a plasticity index of 18 and liquid limit of 35. Life Cycle Costs (LCC) of the soil stabilization treatment and asphalt wearing surfaces were unknown in 2009. Other concerns included appropriate treatment thickness, allowable traffic loadings, and repair and maintenance practices.

Despite those issues, 59 miles of gravel surface road were stabilized with Portland Cement between 2010 and 2013. The initial cost of clay stabilization was generally less than half that of traditional hot mix asphalt and base aggregate, depending on project location relative to gravel pits. A biennial evaluation program was adopted by Richland County using falling weight deflection (FWD) testing and mechanistic analysis to help determine LCC.

After eleven years, the performance of Portland Cement stabilized clay appears very cost effective, despite considerable wearing surface maintenance issues. This paper provides the design methodology and findings during the design, construction, and maintenance phases between 2010 and 2021. A more detailed 50-page report on the project may be found in Reference (*1*).

Methodology

The project design included these steps:

- testing subgrade soils for strength with dynamic cone penetrometer (DCP) (ASTM D6951).
- preliminary cost analysis of different structural sections.
- sampling and laboratory testing of subgrade soils for unconfined strength using Portland Cement, lime, and fly ash (ASTM D559 and D1653).
- vacuum saturation of unconfined strength specimens to predict weathering resistance.
- refining cost estimates for various structural sections; and
- developing construction specifications that included comprehensive quality and quantity assurance (QQA) procedures that were reviewed by prospective bidders.

The construction contract was awarded through a contractor that had an alternative delivery contract with Richland County. This arrangement allowed the selection of a contractor that provided what was believed to be the best value for the county.

The consulting firm hired for QQA was employed by the county.

The first season (2010) consisted of building road segments with differing thicknesses of soil cement with differing types of bituminous surface treatment (BST) and aggregate wearing surfaces. Designs for the following seasons were primarily based on construction costs and FWD testing results. After three years of service, repair areas were delineated by DCP testing and full depth repairs made by the Richland County Road crew.

Findings

The design subgrade California Bearing Ratio (CBR) was three for the lean clays, and one where subsurface drainage problems existed. Initial treatment depths varied from 8 to 12 inches at cement content producing unconfined strengths of 250 to 300 psi. After the FWD evaluation of 2010 and 2011 projects, 12 inches was chosen as the design thickness because good densities and strengths could be achieved with this depth.

In 2011, road soft spots were treated by increasing the cement content by two percent and increasing treatment depth by two inches. After FWD testing in 2012, the soft spot treatment was changed to three percent cement and mixing to 18-inch depths. Two to three days after treatment of soft spots, the whole road was stabilized to the 12-inch depth with additional cement. Some repair areas were later found in subgrade soft spot areas that were overlooked. Other repair areas existed where cement contents were low due to poor construction practices. Those practices were improved in 2012 and 2013.

Most of the soil cement roads were built with a double BST wearing surface placed directly on soil cement. This design was the least expensive since it did not include aggregate base that was costly where projects were a long haul from rock pits. However, extensive BST maintenance and soil cement strength losses due to rubbleization proved this design approach was not cost effective. A much better design using a three-inch-thick aggregate base layer was used on projects that were closer to aggregate sources. The aggregate base layer eliminated the need for trimming soil cement to an accurate crown, lowered cost and improved water curing of soil cement, prevented soil cement rubbleization and strength loss problems, and increased overall strength by increasing the structural section thickness.

Based on biennial FWD testing for eleven years on various thicknesses, and considering maintenance work on different wearing surfaces, the suggested design is shown in Figure 1. Some short sections included a three-inch layer of hot mix asphalt where FWD deflections were less, but costs were considerably higher.

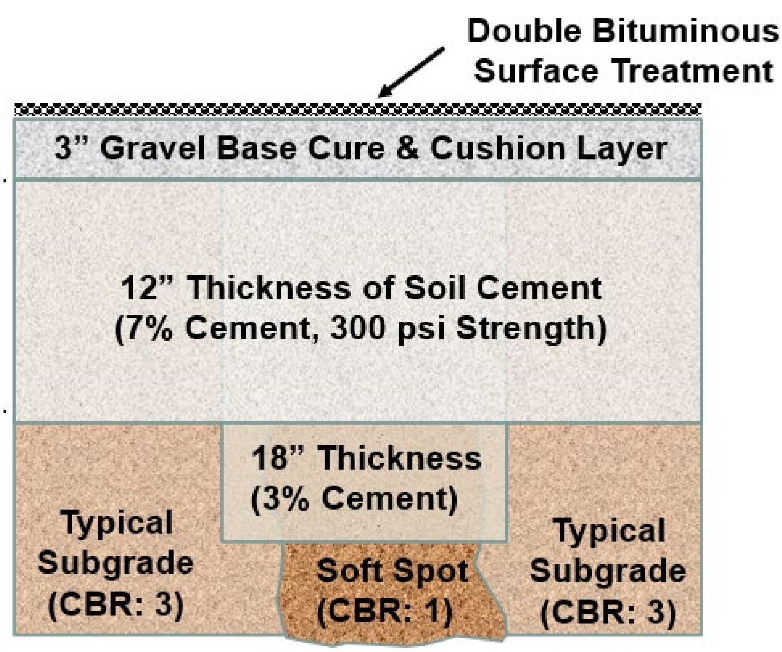


Figure 1. Most Cost-Effective Structural Design

Figure 2 shows a history of soil cement flexural strength for three different types of structural sections. The 2021 data for these curves is shown in Appendix I. After 11 years, soil cement flexural strengths were two to six times that of typical aggregate base, depending on the structural section.

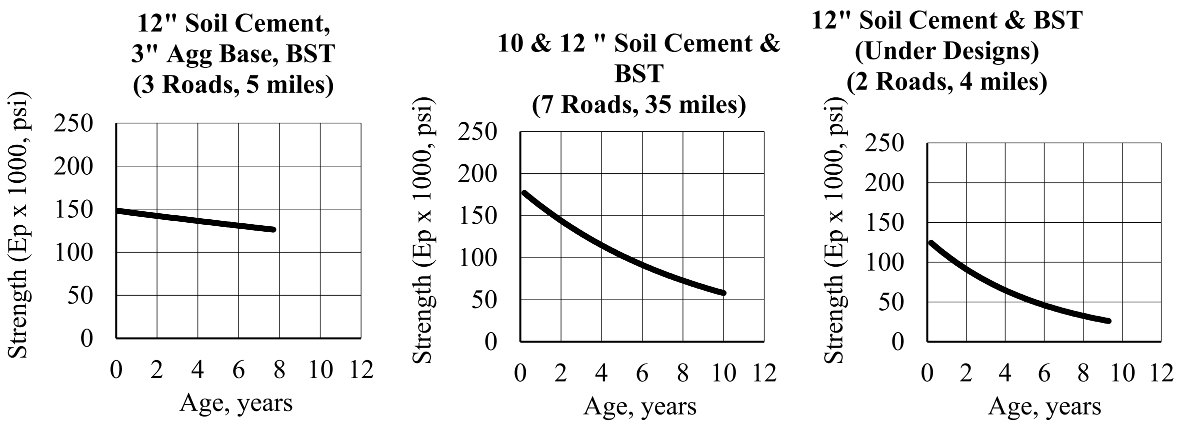


Figure 2. History of Soil Cement Flexural Strength for Various Designs

The FWD back calculation analysis results shown in Appendix 1 provides projected life of each of the 16 roads tested between 2010 and 2021. One simple indicator of structural strength is the maximum deflection directly under the FWD load point indicated in the Column heading “D0”. Values under 20 mils are exceptionally strong, those between 20 and 40 are good and values above 50 are on the verge of failure.

When stabilization with Portland Cement started in 2010, no contractors with soil cement experience existed within 1000 miles of Richland County. In early 2011, a stabilization contractor from Seattle and a cement treated base contractor from Forsythe Montana were selected. Although stabilization of 4000 feet of road per day was impressive, the stabilization contractor expertise was generally unimpressive. All contractors had difficulty appreciating the significant differences between clay subgrade stabilization and full depth reclamation of asphalt roads or cement treated base. None were familiar with clay pulverization requirements and the need to routinely clean mixing chambers to obtain uniform moisture contents when stabilizing clays. However, the ability to haul 200 to 300 tons of Portland Cement per day over 500 miles and then store and handle that amount day after day for several months was impressive.

In 2011, a more detailed QQA specification was developed by County consulting engineers to reduce the 10 percent soil cement rebuild requirement traditionally indicated by contractors. The critical measurements covered by the new QQA specification were cement spreading accuracy, treatment thickness, clay pulverization, moisture content, compaction by pad foot and pneumatic rollers, unconfined strength testing, finishing to a smoothness standard suitable for BST on soil cement, and asphalt cure membrane on the soil cement. The QQA work cost less than five percent of the soil cement construction costs and reduced repairs to less than two percent of the miles built.

One of the most beneficial practices developed during construction was building centerline alignment and shoulder berms and pre-ripping the road surface to control cement flow. These practices reduced rutting failures due to low cement content in the reclaimer wheel tracks.

Most of the repairs on the 2011 work was on the BST driving surface. The 2011 BST was built with high float emulsion application rates that were too high, and the treatment was not rolled enough to complete the emulsion “breaking” process. Asphalt cement BST rates were also too high where clean chips and fabric were used on crowns that were over 2.5%. The double BST built on the soil cement in 2012 by more traditional practices using polymerized rapid set emulsion needed less repair work. Repairs can be reduced significantly if (1) they are done within a week of appearance; and (2) a maintenance chip seal is placed two years after initial BST construction. Spray patching and proprietary open graded cold patch asphalt mixes were found to last longer than hot mix patching. After coping with BST maintenance problems for three years, the general feeling was that the double BST surface should not be built directly on the soil cement where any significant amount of truck traffic is expected. Figure 3 shows rubbleization (fracturing) of soil cement directly under the BST in wheel tracks. A better design and construction approach is to cover the soil cement each day with three inches of base aggregate and chip seal the aggregate surface after all stabilization is completed. The aggregate base layer also provides a soil cement cure layer that improves soil cement strength and durability.

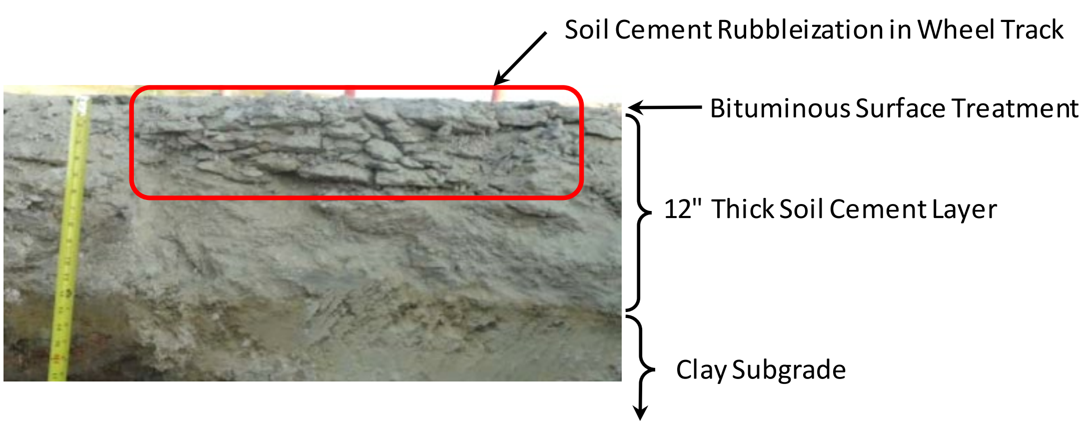


Figure 3. Rubbleization of Soil Cement without Aggregate Base Layer

In 2015 and 2016, repairs to the soil cement treatment were done on the 2011 work, amounting to about 2.5 percent of the miles built. The amount of repair to the 2012 work was less than 0.3 percent. This lower percentage is attributable to a more comprehensive QQA specification and better construction practices. Soil cement repair areas were identified by ruts and depressions in the driving surface and further delineated with DCP testing and probing with a pickax. Repairs were necessary due to one or more of the following problems: combination of low moisture content and compaction, low cement content, and overlooked subgrade soft spots. Most repair areas existed where cement spreads stopped and started, where cement was allowed to flow down the crown, or outside the stabilized road width. Repairs were made by adding six percent cement, mixing enough water to hydrate the cement and achieve compaction, mixing to 12-inch depths, and compacting with a 27-ton vibratory pad foot roller until “walk out”. The soil cement repair area was then double chip sealed. DCP testing of areas that were reworked with just three percent cement showed little increased strength and had to be re-stabilized with six percent cement.

In 2018 the Richland County Road Crew did full depth reclamation with 7 percent cement on Road 326. Road 326 was a BST on six inches of aggregate base on a separation geotextile. This structural section required hot mix patching for about 5 years prior to FDR in 2018. After four years of service, FWD deflections are low, and indicator of high strengths.

In 2022 high volumes of uncontrolled truck traffic from oil well fracking caused extensive BST and soil cement deterioration on Roads 146 East and West. This deterioration emphasized the importance of understanding that soil cement must have a wearing surface since it does not hold up well to traffic abrasion. This damage was repaired by blade laying a 2-to-3-inch layer of hot mix asphalt over affected areas. Time will tell how successful this repair process will be.

Conclusions

Clay stabilization with Portland Cement proved to be a good alternative to traditional paving in Richland County, Montana. Where subgrade soils are suitable for stabilization, initial construction costs and life cycle costs can be significantly less than with traditional paving.

Soil cement life cycle costs can be significantly reduced by (1) pretreating subgrade soft spots; (2) using comprehensive construction specifications; and (3) employing experienced personnel to implement a comprehensive quality and quantity assurance plan.

Weathering resistance by laboratory testing using vacuum saturation was not a good indicator of long-term durability of clay stabilized with Portland Cement because unconfined strengths increased rather than decreased. Newly developed cold climate durability tests (tube suction and freeze thaw chamber tests) were suggested in 2016 as a follow up but were not done due to funding issues. General implications from these recent studies are that strengths should exceed 300 psi to be resistant to freeze thaw durability. Although FWD testing on the Richland County roads suggests good resistance to freeze thaw, reliable durability testing is strongly suggested in the design phase of the mix design process prior to construction.

FWD testing and mechanistic analysis was essential to evaluate soil cement performance and helped refine the design, construction, and maintenance processes. After eleven years, soil cement deterioration leveled off to a strength that was two to six times the strength of gravel base. The best performing soil cement roads include a three-inch layer of gravel between the soil cement and the double BST. Soil Cement with just a BST wearing course will have a short life due to rubbleization from truck traffic.

Continued FWD testing is suggested on a biennial basis. However, if this cannot be done, monitoring of rut depths in selected areas can be a good substitute, especially where truck traffic is or expected to be significant. Where deterioration is significant (as on Road 480 or 143E), use of the Dynamic Cone Penetrometer (DCP) can be invaluable when determining rebuild depths and cement contents.

When soil cement/BST road segments fail, FDR with 5 to 7% portland cement to 12-inch depths is suggested along with a 3-to-4-inch aggregate base layer. If the failure is caused by excessive subsurface moisture, pre-treatment with 3% cement is suggested to an 18-inch depth prior to FDR. Optimum moisture and extensive compaction with vibratory pad foot rollers exceeding 25 tons is critical. Either a BST or AC wearing surface should work well on the aggregate base layer. AC is preferred where truck traffic is heavy.

Contractors with good equipment, intentions, and considerable experience do not necessarily possess a good working knowledge of their construction equipment, variations in soil type, or soil stabilization technology.

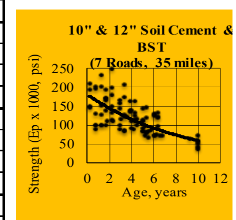
References

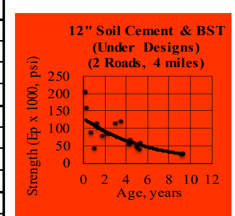
(1) Monlux, Vischer, Soil Cement Roads in Richland County Montana 2010-2015, https://www.mdt.mt.gov/other/webdata/external/research/docs/research_proj/oil_boom/RCSC-03-2015.pdf (Accessed on 11/26/2018)

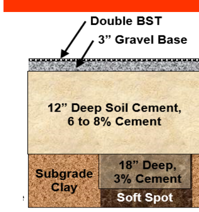
Appendix I: 2021 FWD Results - Richland County Soil Cement Roads (2-10-2022)

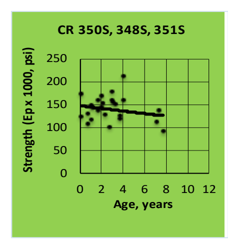
***FWD** (Falling Weight Deflectometer **SC** (Soil Cement - mixture of portland cement and subgrade soil) **ESAL** (Equivalent Single Axle Load - one 5 axle loaded truck has 3 ESALs) **Ep** (Elastic Modulus) **Mr(** Resilient Modulus) **DO** (FWD Pavement Deflection at Load Ctr) **PCA** (Portland Cement Association) **MDT** (Montana Department of Transportation **BST** (Bituminous Surface Treatment) **PC** (Portland Cement) **SG** (Subgrade) **AC** (Asphalt Concrete - hot mix) **FDR** (Full Depth Reclamation)*

Total Thickness (Layers)	*Road #*	*Ep (Avg. & Max)*	*Mr (Max & Avg.)*	*% Error*	*Compressive Strain, Subgrade*	*Radial Stress CS Layer* Comp Stress: Top	Tensile Stress: Bottom	*Comments*	*Age, yrs*	*DO*	*Projected Life in ESALS* PCA (a)	*Asph Inst*	*MDT (b)*
8" (BST on SC)	129W		5.02	0.62	1944			Mr Max					
		93.6	4.9	3.54	1906	122.9	91.8	Ep & Mr Average	**11**				
		100.2		0.21		125.33	94.96	Ep Max					
	Avg.	***96.9***	***5.0***	***1.5***	***1925***	***124.115***	***93.38***			**40**	**(a)**	***7114***	23739
10" (BST w/fabric on SC)	201		5.28	1.1	2467			Mr Max					
		36.1	5.03	7.04	1022.3	87.5	45	Ep & Mr Average	**10**				
		49.4		0.93		96	57	Ep Max					
	Avg.	***42.8***	***5.2***	***3.0***	***1744.65***	***91.75***	***51.0***			**52**	**(a)**	11040	36850
10" (BST w/fabric on SC)	321N		4.26	0.78	2874			Mr Max					
		32.7	4.1	4.12	2838	89	47.4	Ep & Mr Average	**10**				
		37		0.03		92.4	52.26	Ep Max					
	Avg.	***34.9***	***4.2***	***1.6***	***2856***	***90.7***	***49.8***			***61.9***	**(a)**	1216	3988
10" (BST on SC)	143E		4.28	0.39	2443			Mr Max					
		44	4.07	5.76	2394	94	54.7	Ep & Mr Average	**10**				
		56.2		0.75		101	64	Ep Max					
	Avg.	***50.1***	***4.2***	***2.3***	***2418.5***	***97.5***	***59.4***			***52***	**(a)**	2558	7855
10" (BST on SC)	324		6.31	0.63	1711			Mr Max					
		65.82	5.68	6.26	1647	95	57	Ep & Mr Average	**10**				
		80.5		0.55		101.6	64.4	Ep Max					
	Avg.	***73.2***	***6.0***	***2.5***	***1679***	***98.3***	***60.7***			**37.5**	**(a)**	13120	49731
10" (BST on SC)	146W		5.66	0.51	1918			Mr Max					
		53	5.51	3.29	1896	92.8	52	Ep & Mr Average	**10**				
		59.5		0		96	56.7	Ep Max					
	Avg.	***56.3***	***5.6***	***1.3***	***1907***	***94.4***	***54.35***			**43.7**	**(a)**	7419	27611
10" (BST on SC)	146E		5.61	0.78	1961			Mr Max					
		51.6	5.41	6.11	1942	92.6	51.8	Ep & Mr Average	**10**				
		67.24		0.67		100	63	Ep Max					
	Avg.	***59.4***	***5.5***	***2.5***	***1951.5***	***96.3***	***57.4***			**43.1**	**(a)**	6699	24709
12" (BST on SC)	314		5.5	1.26	1521			Mr Max					
		55.3	4.7	9	1481	86	43	Ep & Mr Average	**8-9**				
		74.3		0.45		92.5	52.2	Ep Max					
	Avg.	***64.8***	***5.1***	***3.6***	***1501***	***89.25***	***47.6***			**37.1**	**(a)**	21668	66845
12" (BST on SC)	143W		3.5	0.28	2962			Mr Max					
		21.9	3.3	7.4	2951	79	33	Ep & Mr Average	**8-9**				
		28.1		0.15		83.6	40.4	Ep Max					
	Avg.	***25.0***	***3.4***	***2.6***	***2956.5***	***81.3***	***36.7***			**69.7**	**(a)**	1043	2808
12" (BST on SC)	480		3.72	2.21	2719			Mr Max					
		25.1	3.35	7.94	2694	79.3	35	Ep & Mr Average	**8-9**				
		30.3		1.21		83	40.4	Ep Max					
	Avg.	***27.7***	***3.5***	***3.8***	***2706.5***	***81.15***	***37.7***			**64.2**	**(a)**	1549	4146
12" (BST on 4"Base on 8" SC)	129W		6.8	0.06	1181			Mr Max					
		67	6.5	5.4	1166	46	48	Ep & Mr Average	**11**				
		83.2		0.1				Ep Max					
	Avg.	***75.1***	***6.7***	***1.9***	***1173.5***	***46***	***48***			**29.4**	187000	65100	239103
15" (BST on 3" Base on 12" SC)	350S		10.96	0.02	623			Mr Max					
		79.3	9.3	9.1	631.7	29	21	Ep & Mr Average	**8**				
		108		0.14				Ep Max					
	Avg.	***93.7***	***10.1***	***3.1***	***627.35***	***29***	***21***			**20.8**	42MM	>100MM	>100MM
15" (BST on 3" Base on 12" SC)	348S		11.8	0.38	484.5			Mr Max					
		120	9.7	7.7	480	38	25	Ep & Mr Average	**8**				
		154.5		0.38				Ep Max					
	Avg.	***137.3***	***10.8***	***2.8***	***482.25***	***38***	***25***			**16**	>100MM	3MM	14MM
15" (BST on 3" Base on 12" SC)	351S		17.43	0.12	415			Mr Max					
		106.2	16.29	4.05	416	36	23	Ep & Mr Average	**8-9**				
		120.3		0.09				Ep Max					
	Avg.	***113.3***	***16.9***	***1.4***	***415.5***	***36***	***23***			**15.4**	>100mil	6mil	41mil
13" (BST on 2" Base on 11" SC)	326 FDR **(c)**		11.5	0.7	168			Mr Max					
		169	10.9	3.8	470	45	46	Ep & Mr Average	**4**				
		174		1.9				Ep Max					
	Avg.	***171.5***	***11.2***	***2.1***	***319***	***45***	***46***			**16.5**		4mil	15mil
		Ep/Base			***Compr Strain Subgrade***	***Tensile Strain***		AC Ep @ Deg F					
18" (3" AC on 15" SC)	350Rau School	400/57	10.8	8.06	459	186		400- 80F					
		1400/42	10.8	6.08	430	165		1400- 50F	**9**				
		900/47	10.7	6.82	446	183		400- 65F					
	Avg.	1400/42	***10.8***	***7.0***	***445***	***178***				**16.2**		1.4mil	6mil









For most Soil Cement (SC) designs initially, the CS layer went from the surface to the depth of treatment, (normally 10" to 12" thick) with a thin Bituminous Surface Treatment (BST) layer on top. Because some SC showed early rubbleizaton at the surface with heavy loads, a 3 inch thick aggregate layer was overlain on the SC layer with the BST on top to better accommodate and distribute the heavy wheel load pressures at the surface.

(a) Projected life from the PCA model is not reliable where fracturing exists in the stabilized layer

(b) The MTD model is considered the most reliable predictor of projected life

(c) This FDR was done with 7% PC mixed with a BST, 4" Base & 6" Clay SG)